Indian J. Phys. **74B** (5), 379–382 (2000)

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I J P B
an international journal

A fresh consideration for evaluating mean atmospheric temperature

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Received 29 October 1999, accepted 8 August 2000

Abstract : Variation of mean atmospheric temperature, as calculated from radiosonde data, at millimeter wave frequency band (22–140 GHz), is discussed in the light of ambient ground temperature, water vapour density, integrated water vapour content and surface dew point temperature over a particular location, Calcutta. The empirical study reveals that either the surface water vapour density or surface dew point temperature could be the better predictors for determining the mean atmospheric temperature than the ground temperature over the same place

Keywords Millimeter waves, radiometer, mean atmospheric temperature

PACS Nos. 94 10.Fa, 92 60.Jq

In case of microwave remote sensing of the atmosphere, primarily of water vapour content and ambient temperature, one has to depend either on radar return signal as an active method for probing or on passive sensing by radiometer. For this purpose, absorption and scattering phenomena of microwave signal during its passage through the atmosphere, particularly through troposphere, have to be considered. It is noteworthy to mention that absorption and scattering of the desired signal is termed as *attenuation* as a whole.

The use of ground based microwave radiometric measurement of tropospheric temperature and columnar amount of water vapour is well established by Askne and Westwater [1]. The useful accuracy can be achieved in temperature profiling and in the measurement of columnar water vapour by deploying a comparative study between the radiometric measurement and the radiosonde data analysis [2–5]. But, on the other hand, the evaluation of the desired accuracy in radiometric measurement depends on several factors, as for example, (i) the estimation of water vapour from dew point temperature from the radiosonde data is not exact and (ii) the spatial and temporal humidity profile as obtained from radiosonde data may differ from that obtained from the zenith looking radiometer as the ascending balloon follows a random path during telemetry. Moreover, the other source of error in the brightness temperature measurement by a passive radiometer may creep in through the choice of *mean atmospheric temperature* which is the only parameter in converting the antenna temperature, obtained from the microwave radiometer, to the excess attenuation value.

For the sake of clarity, let a certain volume of the atmosphere, which is considered to be an absorbing medium, attain a temperature T_m by absorbing incident microwave energy from outside, which it re-radiates isotropicaly. The extent of such absorption or emission of energy depends on *fractional transmissivity*, σ, of the atmospheric medium. Thus the radiated energy from the atmosphere is a noise, which enhances the thermal noise temperature by an amount $(1 - \sigma)\, T_m$. Now, if such increase in thermal noise temperature in the receiver is detected as T_a, then T_a could be given by

$$T_a = (1 - \sigma)\, T_m \text{ Kelvin.}$$

Again by definition, the *excess attenuation* A in dB is related to σ by $A = 10 \log_{10} (1/\sigma)$ dB, which can then be expressed as generalized conversion expression of Allnutt [6] by

$$A = 10 \log_{10} \frac{T_m(\nu) - T_c}{T_m(\nu) - T_a(\nu)} \tag{1}$$

where $T_a(\nu)$ and $T_m(\nu)$ are the *radiometric antenna temperature* and *mean or effective atmospheric temperature* respectively at frequency ν and T_c is the cosmic background temperature $\approxeq 2.7$ K.

Thus, in evaluating $T_a(\nu)$ from eq (1) the assumption for the value of the fundamental parameter T_m plays a major source of error. As it is expected, T_m is the function of frequency and three basic radiometeorological parameters · atmospheric pressure, temperature and dew point temperature. T_m has insignificant variation in VHF and UHF bands, but in the microwave and millimeter wave band, the variation of T_m is quite appreciable. So, to assess the extent of variation of T_m in microwave and millimeter wave band, the present authors were prompted to start with the wellknown classic equation of radiative transfer for nonscattering and nonrefractive atmosphere by Chandrasekhar [7]. From the radiative transfer quation, the mean atmospheric temperature, T_m, is defined as [8]

$$T_m(\nu) = \frac{T_a(\nu)}{\int \alpha_\nu(z)\exp[\tau_\nu(0,z)]dz} \qquad (2)$$

where $T_a(\nu)$, the equivalent brightness temperature is given by

$$T_a(\nu) = \int \alpha_\nu(z) T(z) \exp\left[-\int \alpha_\nu(z) dz\right] dz \qquad (3)$$

and $$\tau_\nu(0,z) = \int^{z} \alpha_\nu(z) dz \qquad (4)$$

is known as zenith opacity.

From the available radiosonde data of IMD (India Meteorological Department) collected during 1990–1992 for Calcutta, monthly averaged values of the climatological parameters and using an algorithm based on CCIR recommendation [9] developed from the Millimeter wave Propagation Model (MPM) of Liebe [10], the specific attenuation (neper/km), zenith opacity (neper) and brightness temperature (kelvin) corresponding to few selected frequencies of interest (22.235, 31.4, 53.75, 67.8, 76, 94, 118.75, 120.1 and 125 GHz) at discrete pressure levels are computed. Substitution of these values along with its corresponding values of physical temperature at different heights in eq. (2), provides the values of the mean atmospheric temperature T_m, at the concerned frequencies. For this purpose, the following relationships are used.

Absolute humidity : ρ (gm/m^3) = 216.7 e/T, (5)

where T is the physical temperature in kelvin and e is the vapour pressure in mb and is given by

$$e = 6.1078 \exp\,[5369\,(1/273 - 1/T_d)], \qquad (6)$$

where T_d is the dew point temperature in kelvin.

It may be noted that these frequencies are so chosen that they cover either absorption peaks of water vapour or oxygen molecules or they fall at the wings of such peaks or they represent conventional window frequencies within 22 to 140 GHz band.

The monthly variation of the calculated values of T_m so obtained for the selected frequencies, have been presented in Figure 1, where it is evident that the mean atmospheric temperature T_m takes the highest value of about 295.5 K at 125 GHz and the lowest of about 279 K at 22.235 GHz. Moreover, it also shows that T_m remains more or less constant during the monsoon season (June–September) for all the selected frequencies of interest. This supports the fact that during the monsoon season, the integrated water vapour content is maximum over Calcutta as is depicted in Figure 2. It is to be mentioned here that while calculating the specific attenuation coefficient α (neper/km) for its substitution in eq. (2), it was considered to be the sum of that due to water vapour and oxygen.

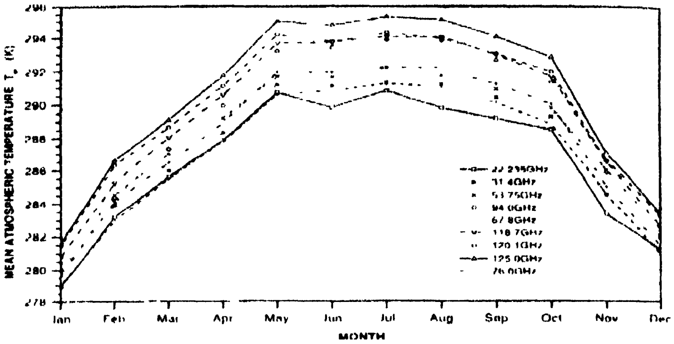

Figure 1. Monthly variation of mean atmospheric temperature for different frequencies Eq (1) has been used for this purpose using 720 radiosonde profiles over Calcutta during 1990–92

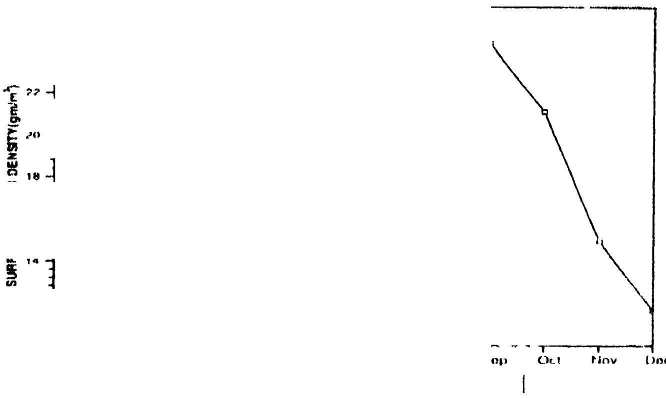

Figure 2. Monthly variation of surface water vapour density over Calcutta during 1990–92 Median values are taken for the purpose Eq (5) has been used for the same

Keeping these in mind, it leads to achieve a linear relationship of T_m with some readily available basic meteorological parameters for obtaining T_a by radiometry, to be validated for a particular location, avoiding lengthy calculation using radiative transfer equation. There were several attempts in the past to express T_m in terms of easily available surface meteorological parameters through simple linear relations. Altshuler *et al* [11] gave an empirical relation for T_m involving ground temperature T_g as

$$T_m = 1.12\, T_g - 50 \text{ Kelvin}.$$

But, often the above relation overestimates the attenuation for ground temperature lying around freezing point. Some of the workers prescribe the value of T_m for a particular frequency or frequency band, for example. Brussard [12] prescribed T_m as 260 K for 11 GHz through data analysis. Since our frequency band of interest is 22 to 140 GHz, similar statistical linear regression analysis has been attempted between the derived values of T_m and surface temperature T_s, based on 720 radiosonde profiles over Calcutta, during 1990–92. The linear relation thus obtained, is given by

$$T_m = AT_s + B \qquad (7)$$

for which the values of the constants A and B are presented in Table 1 along with corresponding correlation coefficients for different selected frequencies.

Table 1. Best fit linear regression coefficients for $T_m = AT_s + B$

Frequency (GHz)	Slope (A) in Kelvin/°C	Intercep. (B) in Kelvin	Correlation coefficient (r)
22.235	0 823	267 383	0 986
31 4	0 857	267 354	0 985
53 75	0 819	269 045	0 982
67 8	0.864	266 800	0 987
76.0	0 911	266 691	0 983
94 0	0 928	268 246	0.988
118 75	0 966	266 975	0 982
120 1	1 004	265 570	0 979
125 0	0 998	267 288	0 985

Another set of similar regression relations have been determined between the calculated values of T_m with surface dew point temperature T_d and with surface water vapour density ρ_0 (gm/m^3). The respective empirical relations are :

$$T_m = C\ T_d + D, \qquad (8)$$

and $$T_m = E\ \rho_0 + F. \qquad (9)$$

The values of the constants C, D, E and F along with the correlation coefficients for different frequencies are presented in Tables 2 and 3

Table 2. Best fit linear regression coefficients $T_m = CT_d + D$

Frequency (GHz)	Slope (C) in Kelvin/°C	Intercept (D) in Kelvin	Correlation coefficient (r)
22 235	0 778	270 05	0 985
31 4	0 816	270 00	0 991
53 75	0 779	271 59	0 988
67.8	0 828	269 36	0 990
76.0	0 870	269 46	0 992
94 0	0 880	271 20	0 990
118 75	0 923	269 89	0 992
120 1	0 963	268 53	0 992
125 0	0 950	270 39	0 991

Table 3. Best fit linear regression coefficients for $T_m = E\rho_0 + F$

Frequency (GHz)	Slope (E) in Kelvin/°C	Intercept (F) in Kelvin	Correlation coefficient (r)
22 235	0 748	272 15	0 979
31 4	0 786	272 18	0 987
53 75	0 749	273 70	0 982
67.8	0 799	271 55	0 988
76 0	0 838	271 77	0 988
94.0	0 846	273 57	0.985
118.75	0 889	272 35	0.989
120 1	0.929	271 07	0 989
125.0	0 915	272 92	0 987

It is noteworthy to mention that the correlation of T_m with T_d and ρ_0 are found to be marginally better than that with surface temperature T_s (Tables 1–3).

According to Ulaby *et al* [13], T_m is usually estimated from the surface temperature. Based on 24 radiosonde profiles, Wu [8] developed a simple relationship of the form $T_m = aT_s$. He found that $a \simeq 0.95$ for several frequencies between 20 and 24.5 GHz and $a \simeq 0.94$ for 31.4 GHz, while in our case, the value of the regression constant for 31.4 GHz is approximately 0.86 (refer to Table 1) with a correlation of 98%. However, it may be mentioned here that these regression constants make no sense unless frequency and the nature of the profiles of the meteorological parameters are precisely defined

It is evident from the result that such calculations could only lead to most realistic T_m for a region having a particular climatological pattern. Here, Calcutta could be considered as the representative of humid tropical regions. Similar empirical relations for T_m could be formulated for other regions with different climatological patterns. At this point, the present authors prescribe to use either the dew point temperature T_d or the surface water vapour density ρ_0 as the parameters for evaluating empirically, the mean atmospheric temperature T_m.

Moreover, efforts have been put to find out the variation of T_m through out the monsoon months (June–September) and non-monsoon months (October–May). It is revealed from this study that during non-monsoon months, the difference between the maximum and minimum values of T_m for the selected frequencies varies between 13.38 K and 11.25 K while those for monsoon months are lying between 1.65 K and 0.43 K (refer to Table 4). A scatter plot for this purpose is presented in Figures 3a and 3b.

Table 4. Deviation pattern of mean atmospheric temperature during 1990–92 at different frequencies.

Frequency (GHz)	Maximum deviation (ΔT_m) of mean atmospheric temperature T_m in Kelvin: During monsoon months (June-Sep 1990-92)	During non-monsoon months (Oct-May 1990-92)
22 235	1 65	11 74
31 4	0 90	11.55
53 75	1 33	11.25
67 8	1 15	11 47
76 0	1 04	12 15
94 0	1 27	12 70
118 75	1 10	12 85
120.1	0 43	13 15
125 0	1 28	13 38

As discussed previously, referring to Figures 1 and 2, we find that the water vapour content plays a major role in evaluating the mean atmospheric temperature. To exemplify the situation, a monthy variations of integrated water vapour content (gm/m^2), surface water vapour density (gm/m^3) and dew point temperature (°C) have been plotted in Figure 4.

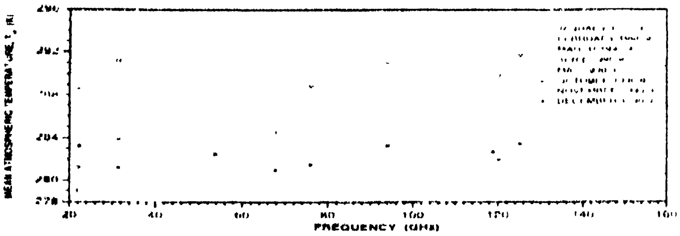

Figure 3(a). A scatter plot of mean atmospheric temperature with frequency (22–125 GHz) during non-monsoon months (Oct.–May) during 1990–92.

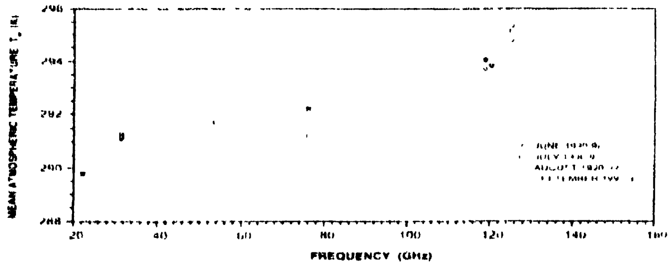

Figure 3(b). A scatter plot of mean atmospheric temperature with frequency (22–125 GHz) during monsoon months (June–Sept.) during 1990–92

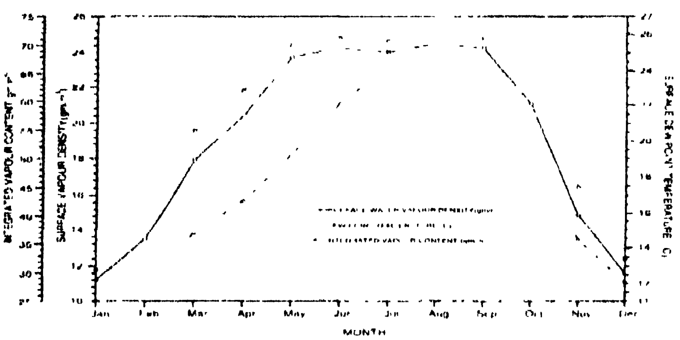

Figure 4. Monthly averaged variation of integrated vapour content (gm/m^2) during 1990–92 over Calcutta corresponding to monthly averaged surface dew point temperature (°C) and surface vapour content (gm/m^3) as calculated from the radiosonde data obtained from India Meteorological Department, Calcutta

It shows that during monsoon season (June–September), the surface dew point temperature and the surface water vapour density bear a flattened peak while that of integrated vapour content extends only through July to August. Also, such monthly variations of the surface water vapour density and the surface dew point temperature have its resemblance with the monthly variation of mean atmospheric temperature (refer to Figure 1). Moreover, Figure 4 indicates that the columnar water vapour takes approximately two months to build-up to form a flattened peak unlike those of surface dew point temperature and surface water vapour density. From these observations, it may be concluded that the mean atmospheric temperature could be determined empirically, more accurately through either by surface water vapour density or by surface dew point temperature rather than integrated water vapour content or by surface temperature.

Acknowledgment

This work is a part of the programme entitled "Training Programme in Millimeter Wave Technology and Wave Propagation" sponsored by the Government of West Bengal.

References

[1] J I H Askne and E R Westwater *IEEE Trans Geosci Remote Sensing* **GE-24** 340 (1986)

[2] M T Decker, E R Westwater and F O Guiraud *J Appl Meteorol* **17** 1788 (1978)

[3] D C Hogg, M T Decker, F O Guiraud, K B Earnshaw, D A Merritt, K P Moran, W B Sweezy R G Strauch, E R Westwater and C J Little *J Climate Appl. Meteorol.* **22** 807 (1983)

[4] M Blaskovic, B E Sheppard, R R Rogers and F C Box *J Atmos Oceanic Tech* **6** 109 (1989)

[5] Chong Wei, H G Leighton and R R Rogers *J Atmos Oceanic Tech* **6** 1001 (1989)

[6] J E Allnutt *Proc IEE* **123** 1197 (1976)

[7] S Chandrasekhar *Radiative Transfer* (New York Dover) (1960)

[8] S C Wu *IEEE Trans Antennas Prop* **AP-27** 233 (1979)

[9] *CCIR Report* Annexure to volume V No 719-3 (1990)

[10] H J Liebe *Int J Infrared Millimeter Waves* **10** 331 (1989)

[11] E E Altshuler, V J Falcone and K N Wulfsberg *IEEE Spectrum* **5** 83 (1968)

[12] G Brussard *ESA Publication* **SP-1071** (1985)

[13] F T Ulaby, R K Moore and A K Fung *Microwave Remote Sensing, Active & Passive, From Theory to Applications* (Reading, Massachusetts Addison Wesley) **Vol III**, Ch 17, p 1332 (1986)